Effective Uplink Data Transmission Scheme for MTCDs in LTE-A Networks

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***Abstract*—With the demand of uplink data generated by massive machine type communication devices (MTCDs) in LTE-A networks, the traditional radio access and resource allocation schemes are not suitable for IoT applications. Because, comparing to traditional human type communications, the machine type devices need much more access frequency but with much smaller data volume each time. In this paper, we propose the novel random access scheme for MTCDs together with piggyback small data in Msg3 of the random access procedure to improve the uplink data transmission performance. The implicit preamble reservation concept is applied to prevent dense random access so as to increase the access success ratio. The contention-free preambles together with small data are supported for the devices which definitely have data to transmit. Two approaches, Limited Buffer Threshold Algorithm (LBTA) and Limited SCH Capacity Algorithm (LSCA) are proposed and their performance are compared. The simulation results show that the proposed schemes illustrate good performance in transmission delay and effective preamble utilization.**

Keywords— Machine Type Communication, LTE-A, Random Access, Preambles

I. INTRODUCTION

Internet of Things (IoT) technology has been widely applied in many fields for the provisioning several advanced services, such as big data analysis, machine learning, intelligent environment management and control, etc.. Generally, the information collection, which is sensed or collected by the end devices, is the essential and basic step toward various kinds of applications in IoT. The collected information needs to be transmitted to the servers or cloud through communication networks. The rapid development and deployment of internet of things (IoT) services greatly alter the wireless communication technologies [1]. Because, comparing to the traditional human communication services, there are much more end devices in IoT application environment and the frequency of data generation and data volume to be delivered by each device tends to higher and smaller, respectively.

In order to support the transmission requirement of IoT, The 3rd generation partnership project (3GPP) proposed the machine type communication (MTC) and narrow band IoT (NB-IoT) to compensate the traditional Long Term Evolution (LTE) technology especially for the random access procedure [2, 3, 4]. In the above two approaches, the base station, i.e. eNodeB (eNB), provides preambles to regulate the contention procedure. The number of preambles can be divided into contention based and contention free parts. The contention free preambles are assigned to designated MTC devices (MTCDs) by eNB. In NB-IoT, it provides flexible preambles arrangement by adjusting non anchor carriers to support more preambles if the number radio access increases. Their random access procedure are similar as shown in Figure 1.

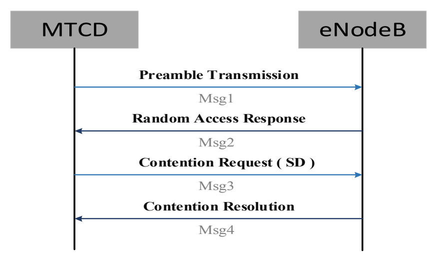


Figure 1 Random Access Procedure of LTE Networks

The random procedure provides the contention resolution in two stages. In the first stage, MTCD, which has data to be delivered, shall randomly chooses a preamble to notify eNB in Msg 1, and eNB will response the preambles that are issued in Msg 2. The eNB can only sense whether the preamble is issued or not, it cannot differentiate whether the preamble is issued by one or more MTCDs. In stage 2, for the MTCD shall send the Msg 3, contention request message, if its preamble is responded by eNB. It is noted that there may be more than one MTCD sends MSG 3 by using the same preamble. And eNB will reply the contention resolution for the request without collision in MSG 4. In MSG 4, eNB will also inform the MTCD for the allocated radio resource to uplink its data in the share channel (SCH). As the data volume generated by the sensor device is much smaller than the tradition services (c.f. video streaming), MTCD can piggyback the small data (SD) together in MSG 3 to save the radio resource in SCH. The objective of this paper is to tradeoff the arrangement of contention free preambles with SD transmission (SDT) and the SCH for effective resource utilization. The proposed algorithm effectively arranges the contention free preamble to suitable MTCD to deliver its data in MSG 3 so that the number of devices in contention of preambles and the utilization of SCH resource can be decreased.

The organization of this paper is as follows. The related works are overviewed in the next section. The proposed algorithms are described in the section III. In section IV, the performances of the proposed algorithms are compared with discussions through exhaustive simulations. And the concluding of our works is provided in the last section.

II. RELATED WORKS

As mentioned in previous section, the number of IoT devices is much more than the number of traditional human devices. It introduces huge number of radio access demands and may cause high collision. Then the information successful delivery rate will decrease and as a result, the performance of IoT service quality will be downgraded. In order to relax the occurrence of collision in random access procedure, the access baring class (ACB), separation of RACH resource, and back off adjustment schemes were proposed in [5]. The basic concept of their scheme is to ease the preamble contention by separating the preambles for different kinds of usages and adjusting the back off window of devices. In [6, 7], the small data concept was introduced and eNB allocate the specific preamble with SDT ID to MTCD to piggyback its small data (e.g. 33 bytes) in Msg 3. The bearer connection management was considered in [7] to avoid the connection re-establishment overhead when MTCD has new data for uplink in short time.

For the arrangement of contention free preambles, the authors proposed to provide the contention free preambles to the specific MTCDs that has fixed traffic arrival pattern in [8]. In [9], the code expanded access was proposed to allow MTCD to issue its preamble in multiple slots. And this scheme was extended to let MTCD utilize multiple preambles in multiple slots in [8]. In this scenario, eNB maintains a hash table for MTCD to choose proper preambles.

For the hybrid human type and machine type communication environment, in [10, 11], the preambles were arranged into groups and UE shall contend its associated preamble group for random access. And each preamble group represents a kind of quality of services (QoS). The main purpose of this approach is to provide eNB to effectively allocate radio resource in SCH. In [12], the authors proposed the access class barring (ACB) mechanism for two-stage admission. Their scheme restrict the number of random access in the first stage so that the collision can be minimized and the devices that are not admitted in the first stage can join the random access in the second stage if there is residual bandwidth in SCH.

Although the above researches proposed the schemes for preamble contention, SD piggyback and the radio resource allocation in SCH, they did not consider them from the correlation point of view. In this paper, we discuss the arrangement of contention free preamble with SD and correlated it with the resource utilization of SCH in the following section.

III. THE PROPOSED ALGORITHMS

As mentioned in previous sections, the data volume to be delivered by MTCD is relatively small when comparing to traditional communication services. And the supporting of SDT capability in random access procedure provides the possibility to deliver data without using the resource in SCH if the MTCD wins the contention in Msg 3. The basic concept of our approach is to tradeoff the using of contention free preambles and the allocation of SCH radio resource for MTCDs that successfully send contention request message (Msg 3) to eNB. The MTCD is designed to piggyback one unit of data (e.g. 33 bytes) in Msg 3 and report the residual data in its backlog buffer. This message will be either successfully decoded by eNB or fail (e.g. collision). For the successfully received Msg 3, eNB will decide whether to allocate the bandwidth in SCH for its further transmission or arrange contention free preamble(s) in the following random access periods. And the MTCD shall piggyback one unit of data in each of its assigned contention free preamble with SD. In the proposed scheme, eNB plays the role of the decision maker to determine whether to allocate SCH resource of this random access period(s) or the contention free preamble(s) in the following random access period(s) for the successful MTCD in Msg 3. For the successful MTCD, it may either receive the allocated resource of SCH in contention resolution (i.e. Msg 4) or receive the assigned contention free preamble in system information block (SIB) message of the next contention period. If the MTCD does not receive the allocated bandwidth in Msg 4 nor the contention free preamble in the next contention period, then it is fail in sending Msg 3 and shall join the contention procedure again. Comparing to the traditional procedure, the MTCD may not join the contention of the random access procedure when it has data waiting for uplink because it expects to receive the assignment of contention free preamble in the following contention period. Then we design the state transition diagram in Figure 2.

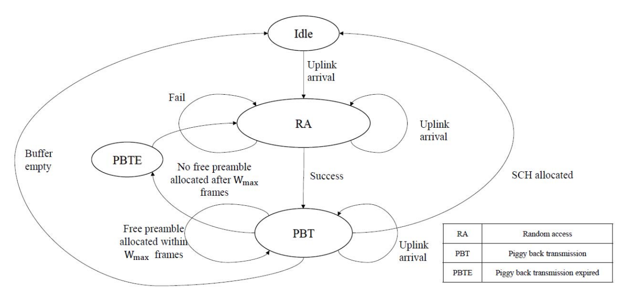


Figure 2 State Transaction Diagram of MTCD

If eNB allocates the SCH resource to the MTCD after the success of random access (RA), then it follows the traditional scheme to uplink data. Otherwise, the MTCD enters the piggyback transmission (PBT) state to wait for the contention free preamble in the following random access periods. The MTCD will keep staying in the PBT to piggyback small data by using the assigned contention free preamble (assuming 1 data unit/preamble), and if the MTCD is not assigned the contention free preamble for W_{max} random access periods and it has data in its backlog, it will enter the RA state and join the random access procedure. It is noted that the MTCD in the PBT state will not join the random process and can relax the contention traffic in random access procedure. The detail flow chart of the MTCD operation is provided in the Figure 3. The state of MTCD is also specified with each operation.

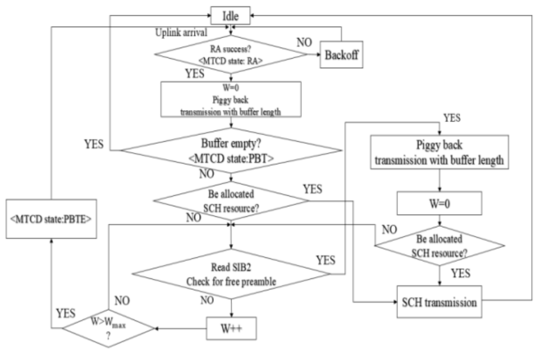


Figure 3 The Operational Flowchart for MTCD of the Proposed Algorithm

For the operation of eNB side, two approaches are proposed in this paper. The Limited Buffer Threshold Algorithm (LBTA) decides whether to allocate contention free preamble depending the number of residual data unit in the MTCD backlog. And the Limited SCH Capacity Algorithm (LSCA), under the constraint of the SCH capacity that is pre-allocated for MTCD usage, allocates MTCD with the SCH resource.The procedures of the LBTA and LSCA are given the figures 5 and 6, respectively. It is noted that the MTCD operation (in Figure 3) is the same for both eNB algorithms.

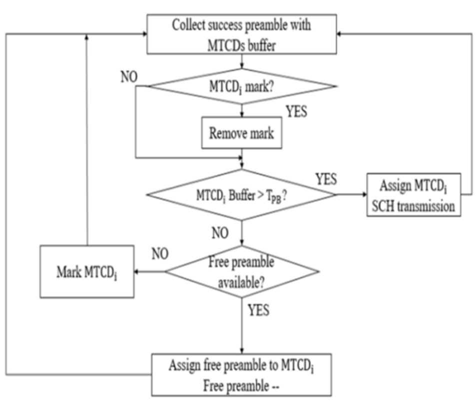


Figure 5 The Proposed LBTA Algorithms

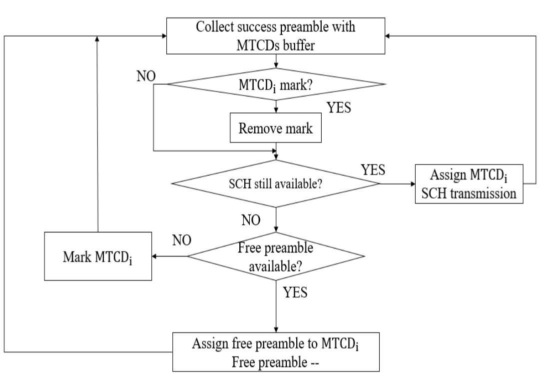


Figure 6 The Proposed LSCA Algorithms

It is noted that the proposed algorithms also define the number of upper bound for the number of contention free preambles so as to provide contention possibility for other MTCDs. And if there is no contention free preamble left for MTCD, eNB will mark the MTCD so that eNB may assign the contention free preamble in the next random access period. However, as the MTCD does not eNB mark it, it will still contend the preamble if it does not receive the assignment of the contention free preamble in the next random access period. MTCD does not need to know which kind of the algorithm performed by eNB. Thus, from MTCD point of view, if it does not receive the allocated bandwidth in SCH nor the contention preamble, it will join contention for preamble.

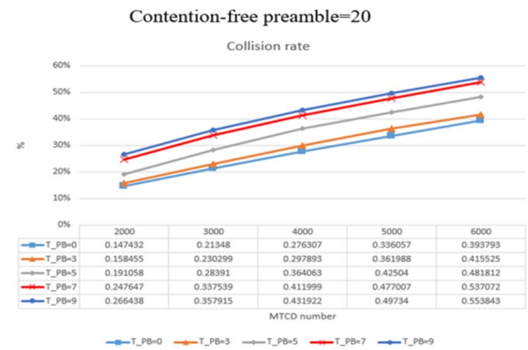
IV. Performance Simulations

In order to examine the performance, exhaustive simulations for both of LBTA and LSCA algorithms were performed to conduct the effectivity of the proposed algorithms. Table 1 illustrates the parameters used during the simulations.

Table 1 Simulation Parameters

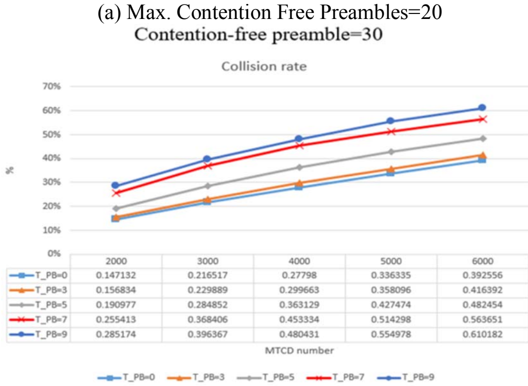
Simulation Parameters	**Values**
Number of MTCDs	2000/3000/4000/5000/6000
Max contention-free preamble	20/30
RA period(ms)	5
Simulation time(ms)	20000
Traffic model	Poisson distribution
Poisson mean rate	0.002
Packet arrival count	Uniform (1,3)
Harq max retransmission times	5
Backoff window(ms)	20
LBTA buffer threshold(T_PB)	0/3/5/7/9
Max waiting frames	3

Figures 7(a) and 7(b) illustrate the collision rates of MTCD when the maximum numbers of contention free preambles are 20 and 30, respectively, for LBTA. The figures show that the collision rate of contention based preambles increases as the number of MTCD increases. The results also illustrate that the collision rate is a little higher for the maximum contention free preambles being 30. Because, in this case, the number of contention based preambles may be only 64-30=34, which is a little less than that of being 20, which is 64-20=44. It also shows that the collision rate also increases as the parameter T_PB increases in Figure 7. Because, as T_PB increases, the scheme tends to not allow the MTCD with less backlog to be allocated for SCH resource and the number of MTCDs join the preamble contention increases and, therefore, more collisions in contention preambles. It is noted that the backlog of the MTCD will keep increasing before it successfully obtains a preamble. In the traditional scheme, MTCD will be allocated with SCH resource, which is the special case of the proposed scheme by letting T_PB=0, and there is no need for the contention free preambles, as a result, the collision will be the least, however, it requires the most SCH resource. The difference between the results of SCH requirement for T_PB=0 and T_PB=7 or 9 is about 50% as shown in Figure 8 when the number of contention free preambles is 30.



	2000	3000	4000	5000	6000
T_PB=0	0.147432	0.21348	0.276307	0.336057	0.393793
T_PB=3	0.158455	0.230299	0.297893	0.361988	0.415525
T_PB=5	0.191058	0.28391	0.364063	0.42504	0.481812
T_PB=7	0.247647	0.337539	0.411999	0.477007	0.537072
T_PB=9	0.266438	0.357915	0.431922	0.49734	0.553843

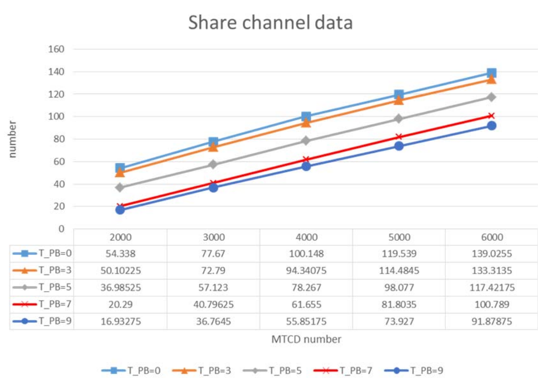
(a) Max. Contention Free Preambles=20



	2000	3000	4000	5000	6000
T_PB=0	0.147132	0.216517	0.27798	0.336335	0.392556
T_PB=3	0.156834	0.229889	0.299663	0.358096	0.416392
T_PB=5	0.190977	0.284852	0.363129	0.427474	0.482454
T_PB=7	0.255413	0.368406	0.453334	0.514298	0.563651
T_PB=9	0.285174	0.396367	0.480431	0.554978	0.610182

(b) Max. Contention Free Preambles=30

Figure 7 Results Collision Rates of LBTA Scheme



	2000	3000	4000	5000	6000
T_PB=0	54.338	77.67	100.148	119.539	139.0255
T_PB=3	50.10225	72.79	94.34075	114.4845	133.3135
T_PB=5	36.98525	57.123	78.267	98.077	117.42175
T_PB=7	20.29	40.79625	61.655	81.8035	100.789
T_PB=9	16.93275	36.7645	55.85175	73.927	91.87875

Figure 8 Usage of SCH Resource of LBTA (Contention Free Preamble=30)

V. CONCLUSIONS

This paper presents two approaches, LBTA and LSCA, were proposed. The LBTA scheme allocates the contention free preamble by referring to the residual data in the backlog of MTCD, whereas the LSCA scheme considers the constraint of SCH bandwidth for MTCD. Both schemes allocate the contention free preamble in efficient way. As some MTCDs are adjusted to deliver their data by using contention free preamble, the contention of preambles can be relaxed. The data transmission delays of the LBTA scheme is shorter than that of the LSCA scheme when the pre allocated SCH bandwidth is rare (e.g. less than 30 data units). In this paper, we only consider the machine type communication, the management of hybrid machine type and human type communications shall be more complex. Additionally, LTE NB-IoT provides flexible non anchor carrier to flexibly adjust the number of preambles for the large access demands of IoT services. The management of preambles and the allocation of radio resource are the critical issues for the success of IoT deployment. And these two topics are our ongoing research directions.

ACKNOWLEDGMENT

This work was supported in part by the Ministry of Science and Technology (MOST) (grant number: 107-2221-E-008 -063), Taiwan.

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